The electroweak transition and the equation of state in the $SU(2)$-Higgs-model

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Abstract

Since the discovery of the Higgs particle at the LHC it is possible to investigate the equation of state for the electroweak transition in the four dimensional $SU(2)$-Higgs-model at physical parameters. Here a line of constant physics and preliminary results on the equation of state for small N_t values are presented. The data was obtained by simulation with a combined heatbath and overrelaxation algorithm.

The electroweak transition

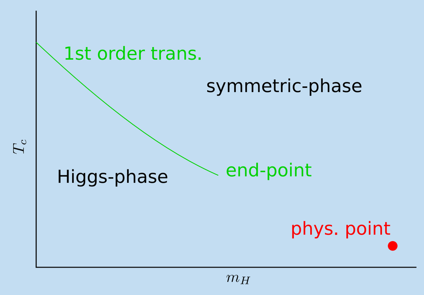
- since 1996: for $m_H \lesssim m_W$ 1st order phase transition for $m_H \gtrsim m_W$ cross over [1]
- since 1998: critical endpoint (66.5 ± 1.4) GeV [2]
- physical:

$m_W = 80.385$ GeV

$m_H = 125.9$ GeV

$m_H > m_W$

$\longrightarrow$ cross over



The $SU(2)$-Higgs-model

- electroweak interaction is $SU(2) \times U(1)$
- in the $SU(2)$-Higgs-model $U(1)$ degrees of freedom are integrated out
- parameters of effective theory are obtained via matching

The lattice action is given as

$$S[U,\varphi] = \beta \sum_{pl} \left(1 - \frac{1}{2} \operatorname{tr} U_{pl}\right) + \sum_x \left(\frac{1}{2} \operatorname{tr}(\varphi_x^\dagger \varphi_x) + \lambda \left(\frac{1}{2} \operatorname{tr}(\varphi_x^\dagger \varphi_x) - 1\right)^2 - \kappa \sum_{\mu=1}^{4} \operatorname{tr}(\varphi_x^\dagger U_{x\mu} \varphi_{x+\mu})\right)$$

The algorithm

For simulations on GPUs and Blue Gene/Q:

- Heatbath-Algorithm
- Overrelaxation-Algorithm

For comparison on CPUs:

- HMC

Successfull cross-check with [3].

The observebels

$$R_x = \det \varphi_x = \frac{1}{2} \operatorname{tr} \left(\varphi_x^\dagger \varphi_x\right) = \rho_x^2$$

$$L_{\varphi,x\mu} = \frac{1}{2} \operatorname{tr} \left(\varphi_x^\dagger U_{x\mu} \varphi_{x+\hat{\mu}}\right)$$

$$P_{Pl} = 1 - \frac{1}{2} \operatorname{tr} U_{pl}$$

$$Q_x = \left(\rho_x^2 - 1\right)^2$$

$$S_x = 6\beta P_{Pl} + R_x + \lambda Q_x - 8\kappa L_{\varphi,x\mu}$$

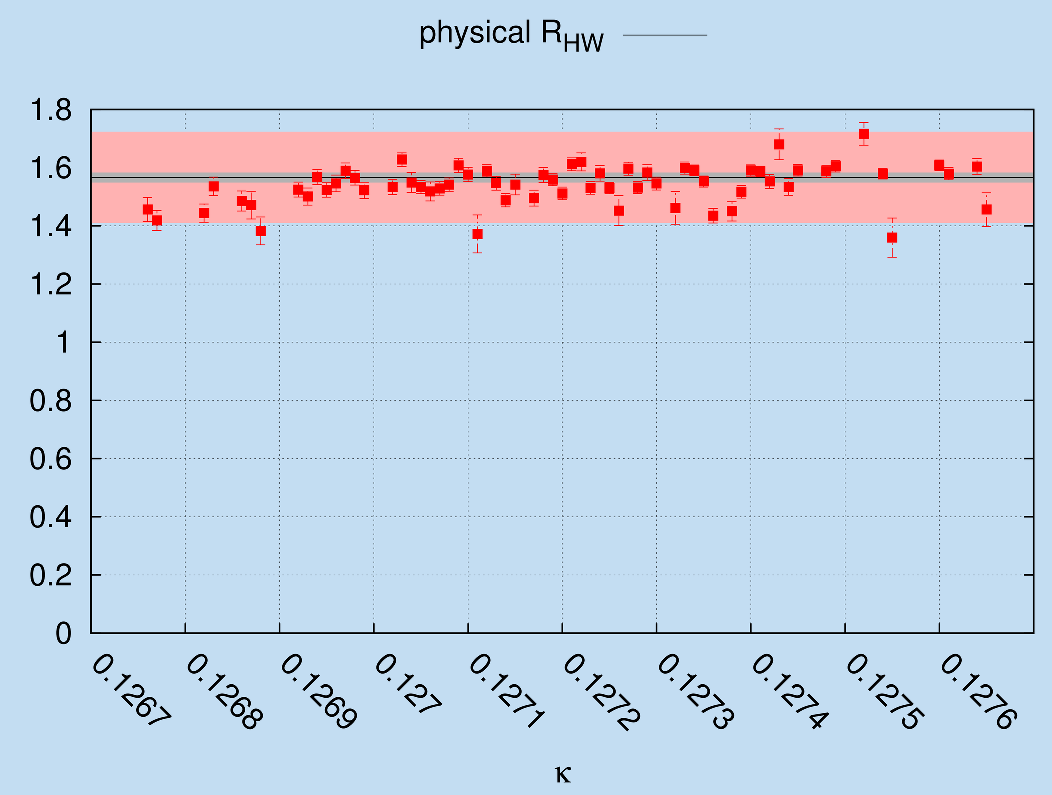
correlators for the Higgs-mass are R_x and $L_{\varphi,x\mu}$ correlators for the W-mass:

$$W_{xrk}^{(n)} = \frac{1}{2} \operatorname{tr} \left(\sigma_r \varphi_x^\dagger U_{xk} \ldots U_{x+(n-1)\hat{k},k} \varphi_{x+n\hat{k}}\right) \text{ [4]}$$

with $n = 2 \ldots 5$

The LCP

- The ratio $R_{HW} = \frac{m_H}{m_W}$ and the renormalized coupling g_R are held constant.
- β is constant and λ depends linear on κ



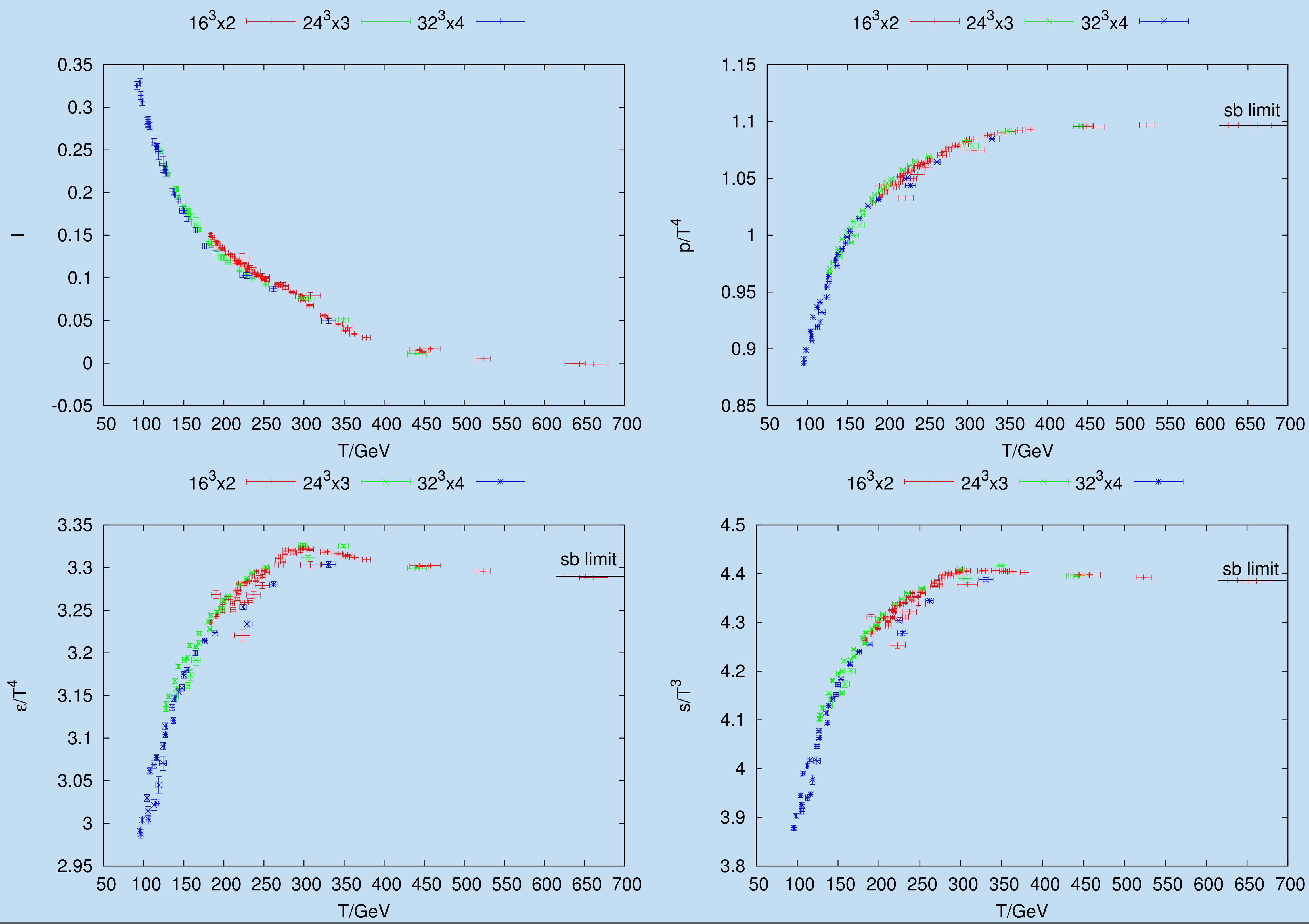
The equation of state

- trace anormaly:

$$I = -N_t^4 m_H \left(-6\langle P_{\mathrm{Pl}}\rangle \frac{\partial\beta}{\partial\kappa}\frac{\partial\kappa}{\partial m_H} - \langle Q\rangle \frac{\partial\lambda}{\partial\kappa}\frac{\partial\kappa}{\partial m_H} + 8\langle L_\varphi\rangle \frac{\partial\kappa}{\partial m_H}\right)$$

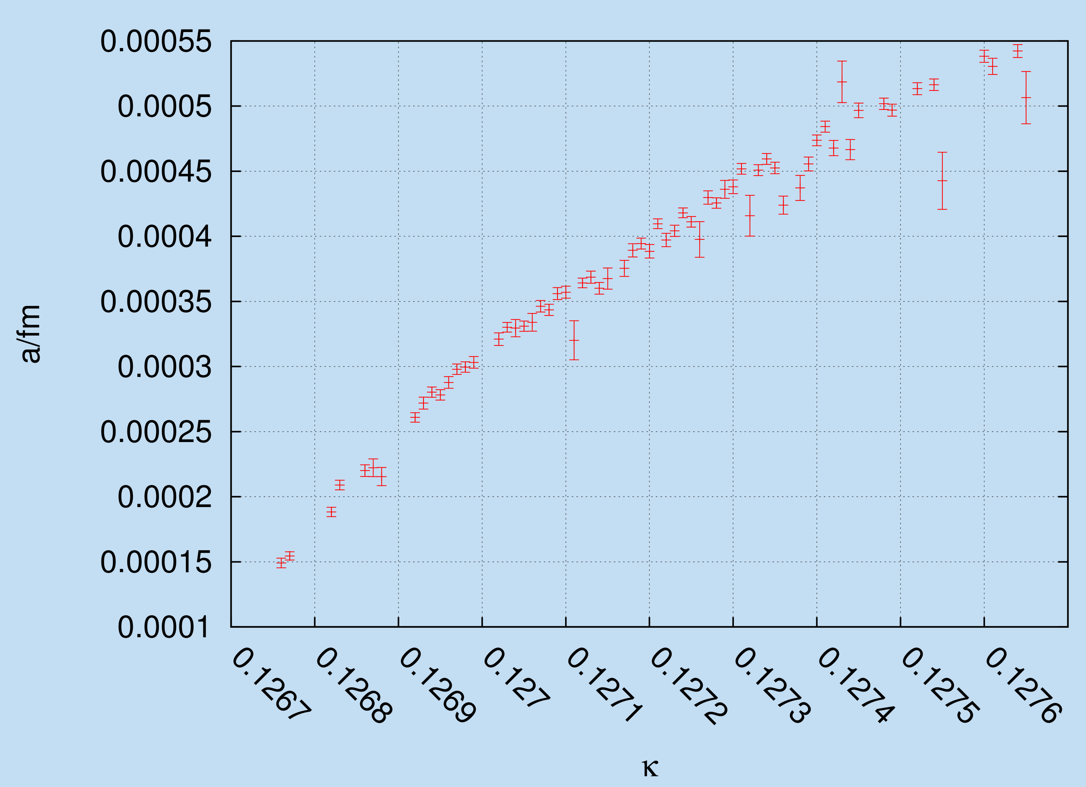
- pressure (offests is mached to sb limit): $p = N_t^4 \sum -6\Delta\beta\langle P_{\mathrm{Pl}}\rangle - \Delta\lambda\langle Q\rangle + 8\Delta\kappa\langle L_\varphi\rangle$
- energy density: $\frac{\epsilon}{T^4} = I + \frac{3p}{T^4}$
- entropy density: $\frac{s}{T^3} = \frac{\epsilon}{T^4} + \frac{p}{T^4}$

Results



The scale

- scale is set with the Higgs mass
- electroweak scale is 0.0008 fm (246 GeV)



References

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